63 3 3

TM(L)-1124 000 00

Satellite Computer Program Description

Milestone 4

Compute Shadow Times

(SHADOW)

TECHNICAL MEMORANDUM

(TM Series)

Satellite Computer Program Description	SYSTEM
Milestone 4	DEVELOPMENT
Compute Shadow Times (SHADOW)	CORPORATION
by	2500 COLORADO AVE.
C. M. Seacat	SANTA MONICA
22 March 1963	
Approved	CALIFORNIA
J. D. Marioni	

INTRODUCTION

SHADOW is a 1604 COP-controlled program designed to compute the times at which a satellite enters and leaves the shadow of the earth.

1.0 IDENTIFICATION

Compute shadow times (SHADOW)

2.0 FUNCTION

The inputs to this program are a reset tape containing orbital conditions and a function card specifying a time range and a time increment. The latter is the time between computations and is equivalent to accuracy desired. The output is an on-line printout of shadow periods (see Section 6.0).

3.0 MATHEMATICAL FORMULATION

The following assumptions are made:

a. The shadow of the earth is cylindrical and non-fuzzy.

b. The positions of the satellite and the sun are known for a given time, t, in inertial coordinates.

The coordinates of the sun at time, t, are (x,y,z). The axis of the cylinder formed by the shadow of the earth passes through the point $(-x,-y,-z)$.

The coordinates of the satellite at time, t, are (ξ, η, ζ).

The equation $\rho^2 = \xi^2 + \eta^2 + \zeta^2$ defines an earth-centered sphere of radius, ρ, with the satellite on the surface.

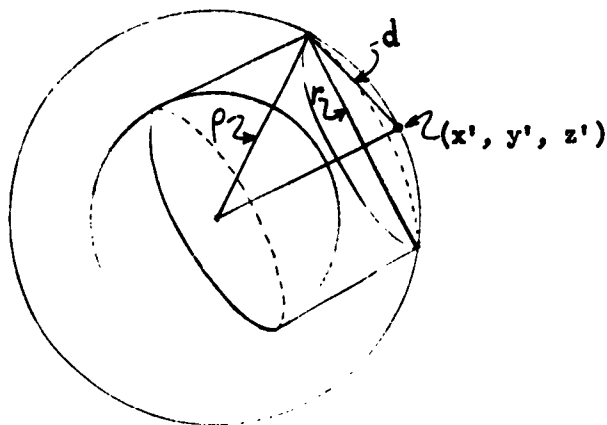The axis of the cylindrical shadow pierces this sphere at x', y', z',
where

$$x' = -\frac{\rho}{R}\, x$$
$$y' = -\frac{\rho}{R}\, y$$
$$z' = -\frac{\rho}{R}\, z$$
$$R = \sqrt{x^2 + y^2 + z^2}$$

Graphically, the situation can be represented as follows:

The distance, d, from (x', y', z') to the circular intersection of the cyclinder and the sphere is given by:

$$d^2 = 2\rho\left(\rho - \sqrt{\rho^2 - r^2}\right)$$ where r = earth radius

The distance, D, from (x', y', z') to the satellite is given by

$$D^2 = (x' - \xi)^2 + (y - \eta)^2 + (z' - \rho)^2$$

If $D^2 > d^2$, the satellite is in sunlight.

If $D^2 \leq d^2$, the satellite is in shadow.

Please note that the analysis above does not assume a circular or near-circular orbit. A new ρ is computed for each t.

4.0 CALLING SEQUENCE

This program is normally called by a function card with the format:

* SHADOW A B C D E F.F G H I J K.K L.L

A	Vehicle number	
B	Month	
C	Day	
D	Hour	Start Time
E	Minute	
F.F	Second	
G	Month	
H	Day	
I	Hour	Stop Time
J	Minute	
K.K	Second	
L.L	Computation interval in seconds	

An option exists to specify start and stop times by rev number. The function card has a format:

* SHADOW   A   B.   C.   D.D

> A   Vehicle Number
> B   Starting Rev (decimal point mandatory)
> C   Ending Rev (decimal point mandatory)
> D.D   Computation interval in seconds

A fractional rev number may be input without harming the program, but the fractional part will be ignored. For consistency between the function card and printed output, it is recommended that zero, or blank, follow the decimal point in the rev number.

Computation is carried out up to, but not including, the terminal rev.

The last field on the card, computation interval, controls the accuracy of the printout and the time consumed by the program. For example, if the computation interval were 60, the printout would be accurate to within one minute. If the computation interval were 1, the printout accuracy would be one second and the program would take roughly sixty times longer. Crude timing estimates indicate that for a computation interval of sixty seconds, the program requires between one and two seconds per rev.

5.0 DETAILED PROCESSES

The program computes the inertial coordinates of the satellite at time, t, by successive branches to the subroutines TTE and PTR. The coordinates of the sun, obtained by table look-up, are taken from the American Ephemeris and Nautical Almanac and contain one value of x, y, and z for each day of the year in the following format.

Location	Contents	
L	x	
L+1	y	December 31, preceding year
L+2	z	

Location	Contents	
L+3	x	
L+4	y	January 1, current year
L+5	z	

.

.

.

Location	Contents	
L+1095	x	
L+1096	y	December 31, current year
L+1097	z	
L+1098	x	
L+1099	y	January 1, next year
L+1100	z	

To get the sun coordinates at a given time, t, the program performs a linear interpolation between successive triads of tabular (x, y, z).

The entries in the table can be transcribed directly from the almanac. Assuming the first address of the table to be tagged SUNCOORD, the first few instruction cards for the 1963 version of the table would be:

	1	2	4
Columns	123456789012	012345678	1 (Comments field)
	SUNCOORD DEC	+.1509848	x, Dec 31
	DEC	-.8914589	y, Dec 31
	DEC	-.3865841	z, Dec 31
	DEC	+.1682445	x, Jan 1
	DEC	-.8888335	y, Jan 1
	DEC	-.3954462	z, Jan 1

.

.

.

(etc.)

6.0 OUTPUTS

Every time the satellite leaves the shadow of the earth, the program
prints on line the date, time, rev number, latitude (geodetic), and longitude
at which it enterred and left. When the stop time is reached, the program
prints out the percentage of time in shadow (i.e., the sum of all the shaded
periods divided by the time range on the function card). A sample printout is
shown in Appendix A.

7.0 INTERFACES AND RESTRICTIONS

The program uses the following subroutines.

Code name

RESET

PTR

LTT

TTE

SETUP

SUBERR

RADDEG

OUTPUT

FLOAT

FIX

RALONG

UTMAC

MACGUT

SQRT

ATAN1

TAN

Once a year the table of sun coordinates (see Section 5.0) must be updated,
and the program reassembled.

Reset tapes containing orbital conditions must be mounted on tape drives
2, 9, and 10.

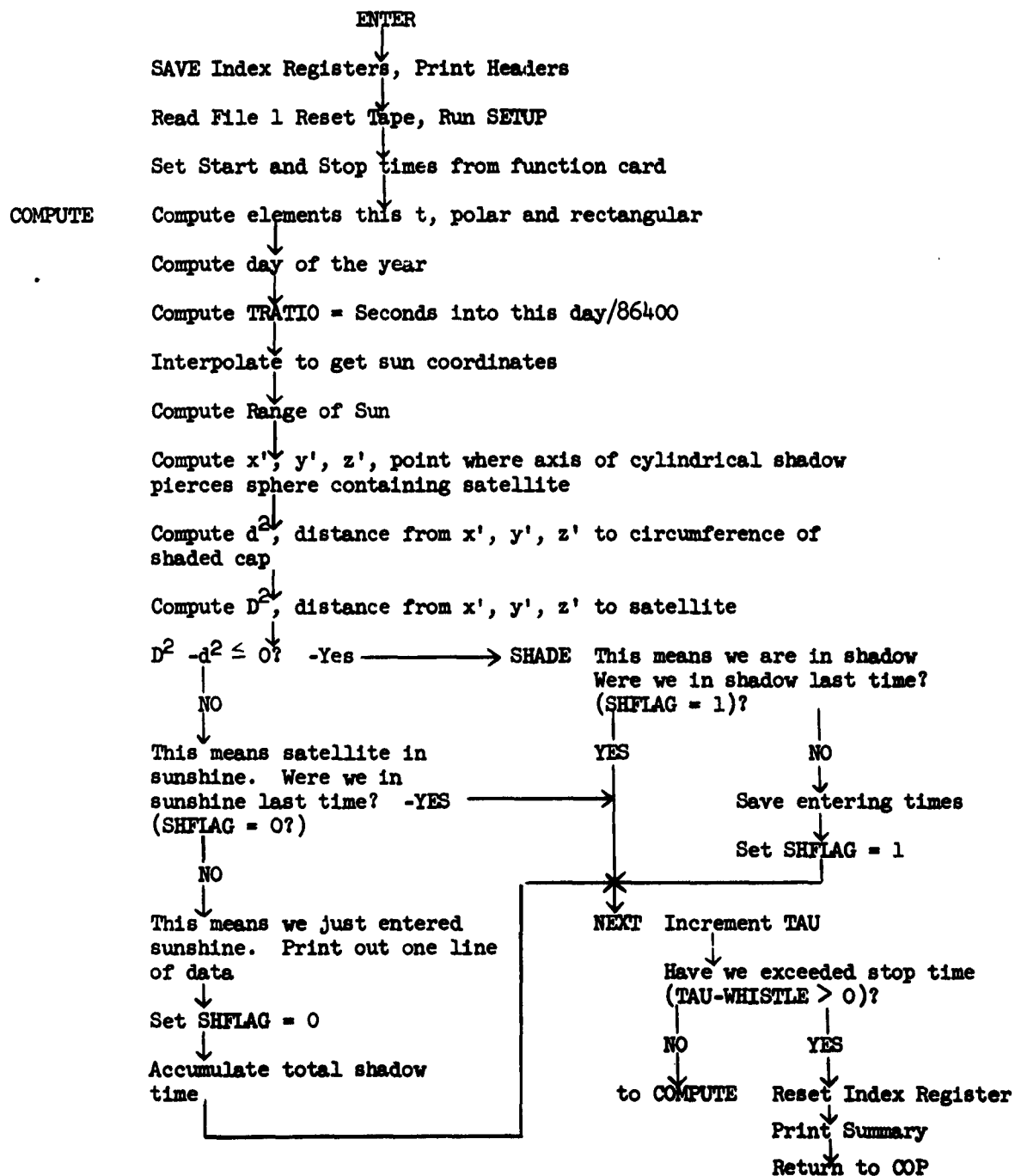To start from scratch, the following function sequence is recommended:

*IRT ...

*WNRT ...

*INJFUN...   (Each card completed appropriately)

*SHADOW ...

8.0 FLOW CHART

ENTER

SAVE Index Registers, Print Headers

Read File 1 Reset Tape, Run SETUP

Set Start and Stop times from function card

COMPUTE   Compute elements this t, polar and rectangular

Compute day of the year

Compute TRATIO = Seconds into this day/86400

Interpolate to get sun coordinates

Compute Range of Sun

Compute x', y', z', point where axis of cylindrical shadow pierces sphere containing satellite

Compute d^2, distance from x', y', z' to circumference of shaded cap

Compute D^2, distance from x', y', z' to satellite

$D^2 - d^2 \leq 0$? -Yes ⟶ SHADE This means we are in shadow. Were we in shadow last time? (SHFLAG = 1)?

NO

This means satellite in sunshine. Were we in sunshine last time? -YES (SHFLAG = 0?)

YES   NO

Save entering times

Set SHFLAG = 1

NO

This means we just entered sunshine. Print out one line of data

NEXT   Increment TAU

Have we exceeded stop time (TAU-WHISTLE > 0)?

Set SHFLAG = 0

NO   YES

Accumulate total shadow time

to COMPUTE   Reset Index Register

Print Summary

Return to COP

APPENDIX A

SAMPLE PRINTOUT

VEH 1136 RUN NO. SAMPLE99
SHADOW INTERVALS TABULATED BELOW

					ENTER				LEAVE					ENTER		LEAVE	
NO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION	GEOD LAT	LONG	GEOD LAT	LONG	
11	1	12	25	0	44700.	9.8	13	0	0	46800.	10.2	2100.	53 15.9S	179 14.2E	88 59.6N	170 27.8E	
11	1	13	55	0	50100.	10.8	14	30	0	52200.	11.3	2100.	47 49.4S	156 40.5E	85 35.9N	32 5.9W	
										(etc)							
11	2	10	35	0	38100.	24.8	11	10	0	40200.	25.2	2100.	52 44.7S	154 10.4W	89 30.5N	162 56.9W	

TOTAL SHADOW TIME 35400. SECONDS FOR 41. PERCENT

External Distribution List

Space Systems Division
(Contracting Agency)

   Major C. R. Bond (SSOCD)
   Major N. D. LaVally (SSOX)

6594th Aerospace Test Wing
(Contracting Agency)

   Lt. Col. A. W. Dill (TWRD)
   Lt. Col. M. S. McDowell (TWRU)
   TWACS   (20)

PIR-E1 (Lockheed)

   J. A. Boysen
   N. N. Epstein
   W. E. Moorman
   G. F. Taylor
   R. L. Vader
   P. E. Williams

PIR-E2 (Philco)

   J. A. Bean
   J. A. Isaacs
   R. Morrison
   S. M. Stanley

PIR-E3 (LFE)

   D. F. Criley
   K. B. Williams

PIR-E4 (GE-Santa Clara)

   D. Alexander

PIR-E4 (GE-Sunnyvale)

   J. Farrentine
   N. Kirby

PIR-E4 (GE-Box 8555)

   J. S. Brainard
   R. J. Katucki
   J. D. Selby

External Distribution List (CONTINUED)

PIR-E4 (GE-3198 Chestnut)

    J. F. Butler
    C. A. Cummings
    H. D. Gilman

PIR-E4 (GE-Bethesda)

    W. L. Massey

PIR-E4 (GE-Box 8661)

    F. T. Clark
    J. D. Rogers
    W. R. Weinrich

PIR-E5 (Aerospace)

    F. M. Adair
    A. Bakst
    J. W. Bengston
    R. V. Bigelow
    R. O. Brandsberg
    L. H. Garcia
    G. J. Hansen   (3)
    L. J. Kreisberg
    M. L. Luther
    T. R. Parkin
    E. E. Retzlaff
    H. M. Reynolds
    D. Saadeh
    R. G. Stephenson
    D. D. Stevenson
    V. White

PIR-E7 (STL)

    A. J. Carlson

PIR-E8 (Mellonics)

    F. Druding

DISTRIBUTION LIST
(CONTINUED) INTERNAL

M. Winsor		22156
J. Winter		24117
R. Wise		22085
J. Wong		Sunnyvale
C. Zubris		24075
AFCPL	(5)	14059

D. Allfree	24083	J. Kneemeyer	22088
J. Aldana	22131	R. Knight	22119
L. Alexander	22134	L. Kolbo	22155
N. Alperin	22153	J Laughlin	24073
E. Armstrong	24123	J. LaVine	24093
C. Becerra	24082	H. Lewis	23010
D. Biggar	24118	J. Little	24088
R. Bilek	23007	F. Long	22156
L. Brenton	24103	J. Lytton	24077
B. Burke	24086	G. Madrid	22081
R. Burke	22158	G. Mahon	24089
R. Busch	22088	J. Marioni	24076
C. Bustya	22134	R. Marshall	22160
M. Champaign	22152	W. Martin	24127
C. Chiodini	24091	J. McKeown	23013
B. Ciaccia	24082	J. Milanese	22155
R. Clements	22109	J. Munson	22087
B. Cline	24127	G. Myers	22095
J. Cogley	22156	P. Nelson	24075
L. Conger	24088	L. Ngou	24127
P. Cooley	24086	M. Olson	22161
D. Crum	24105	L. Padgett	24110
L. DeCuir	24053	E. Patin	Sunnyvale
W. Derango	24082	D. Persico	24083
G. Dexter	25016	T. Polk	24113
R. Disse	23014	D. Reilly	24121
G. Dobbs	22115	A. Robinson	24132
W. Dobrusky	24065	M. Rockwell	24086
R. Dugas	22125	J. Schroeder	24124
R. Ellis	22131	R. Scott	24110
R. Ericksen	22113	C. Seacat	Sunnyvale
H. Feldstein	24128	H. Seiden	22126
C. Francis	25013	R. Shapiro	24110
M. Franks	24122	S. Shoel	23007
L. Friedman	22122	R. Skelton	22152
S. Gardner	25026	N. Speer	24086
V. Gergen	25014	E. Stone	24058
I. Greenwald	22094	M. Sweeney	25026
J. Haake	22153	W. Taber	22101
D. Henley	22094	T. Tennant	27029
C. Hill	22101	J. Thompson	24088
J. Hillhouse	22078	C. Toche	24121
H. Holzman	24065	R. Totschek	24120
G. Hudson	24126	A. Tucker	22109
R. Johnson	22125	A. Vorhaus	24076
P. Kastama	22076	M. Weinstock	22131
M, Katz	25014	S. Weems	22109
F. Kayser	24109	G. West	Sunnyvale
J. Keddy	24105	G. P. West	22116
D. Key	23013	H. Williams	22110
R Keyes	24073	G. Wilson	24124

System Development Corporation,
Santa Monica, California
SATELLITE CONTROL PROGRAM DESCRIPTION
MILESTONE 4 COMPUTE SHADOW TIMES (SHADOW)
Scientific rept., TM(L)-1124/000/00, by
C. Seacat. 22 March 1963, 9p.
(Contract AF 19(628)-1648, Space
Systems Division Program, for Space
Systems Division, AFSC)

Unclassified report

DESCRIPTORS: Satellite Networks.
Programming (Computers).

States that SHADOW is a 1604 COP-
controlled program designed to compute

---

the times at which a satellite enters
and leaves the shadow of the earth.
Also states that the inputs to this
program are a reset tape containing
orbital conditions and a function card
specifying a time range and a time
increment.